Summary of the SPHN activities in PHENIX at RHIC: measuring the J= production in relativistic p+p, d+A and A+A collisions at $\sqrt{s_{NN}}$ = 200 GeV

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CSTS

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Introduction

Motivations

PHENIX, at RHIC started in year 2000. It aims at studying the formation of a Quark-Gluon Plasma in relativistic heavy ion collisions. It is comprised of about 400 scientists and engineers, 40 institutions in 13 countries.

The J/ψ particle is a heavy meson (3.1 GeV) formed of a $c\bar{c}$ pair. It is produced at the early stage of a HI collision via gluon fusion.

A number of effects alter the J/ψ production in HI collisions with respect to p+p collisions:

- Cold Nuclear Matter Effects: modified parton distribution functions; gluon saturation; nuclear absorption; initial state energy loss; etc.
- Hot Matter Effects: Debye like color screening; regeneration via the coalescence of uncorrelated charm quarks

Experimental procedure consists of:

- Measuring J/ψ production in p+p collisions for reference
- Measuring modifications in d+A collisions to study CNM
- Measuring modifications in A+A collisions to evidence the formation of a QGP

SPhN contributions (1)

Our group joined the PHENIX collaboration in 2001.

2 permanent scientists until 2007 + contribution from other members of the Heavy-Ion group.

1 permanent scientist from 2007 until end 2010.

Long term mission at Los Alamos National Lab (18 month) in 2009-2010

PhD Thesis:

- Yann Cobigo (completed in 2005)
  J/ψ production in d+Au collisions
- Catherine Silvestre-Tello (completed in 2008)
  measurement of the J/ψ production's azimuthal anisotropy in Au+Au collisions

SPhN contributions (2)

Hardware:
- Contributed to financing the electronics of one Muon spectrometer.
- Shifts during data taking (as a member of the collaboration)
- Maintenance of the Muon Spectrometer during shutdown between runs

Software:
- Implementation of the Kalman filter used to measure the particle's momentum in the muon arm;
- Implementation of the track-based muon arm detector alignment algorithm (millepede)
- Responsible for the track reconstruction in the muon arms since 2004;
- Responsible for all GEANT simulations since 2006

Analysis:
- Leading contribution to all J/psi related analysis at forward rapidity in p+p, d+Au, Cu+Cu and Au+Au collisions
- Theoretical work (phenomenology) for the interpretation of PHENIX d+Au data in terms of cold nuclear matter effects

Physics publications (1) data analysis

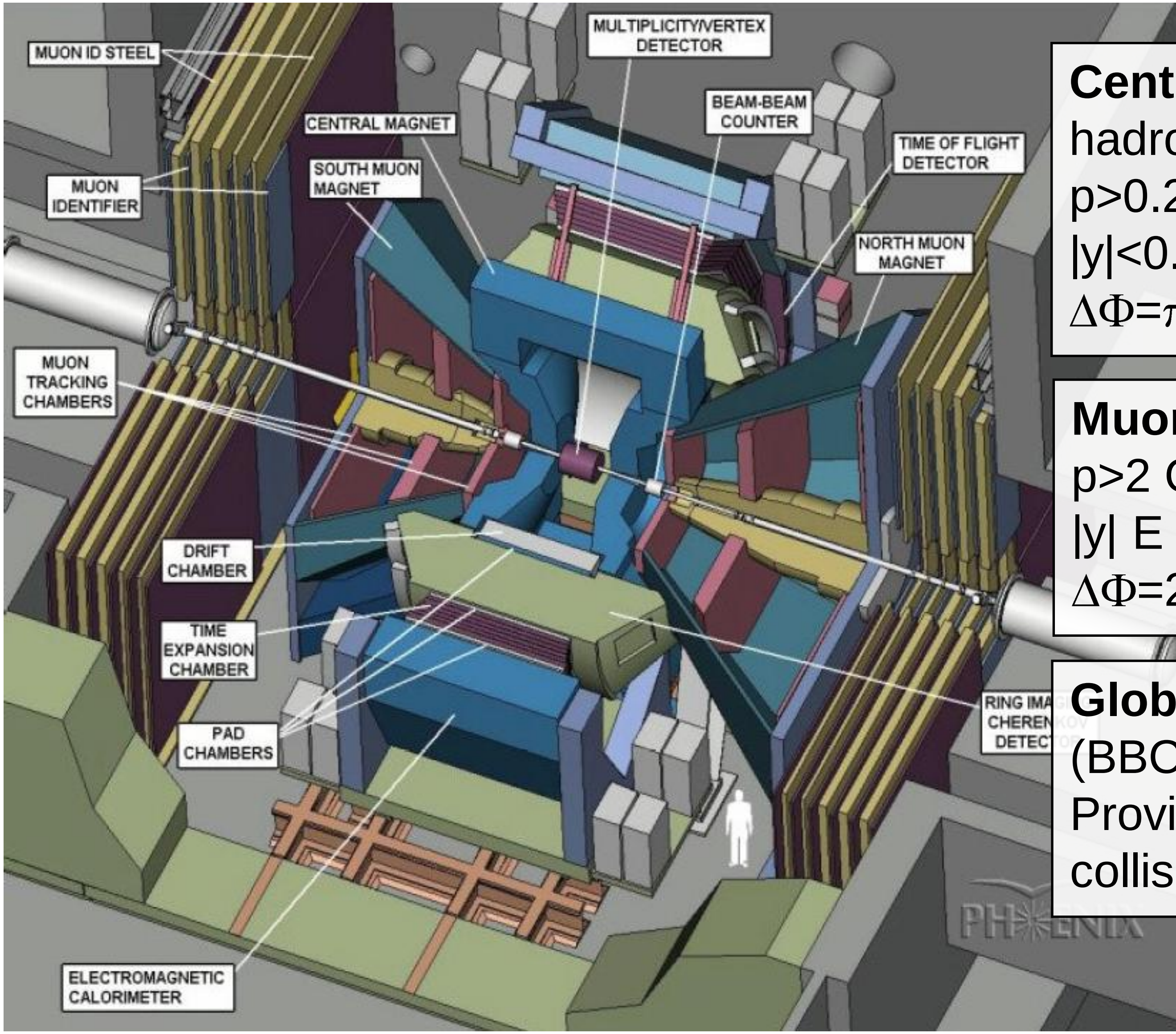
- J/ψ production vs centrality, transverse momentum, and rapidity in Au+Au collisions at $\sqrt{s_{NN}}$= 200GeV. Phys. Rev. Lett., 98:232301 (2007)
- J/ψ production versus transverse momentum and rapidity in p+p collisions at $\sqrt{s_{NN}}$= 200GeV. Phys. Rev. Lett., 98:232002 (2007)
- J/ψ Production in $\sqrt{s_{NN}}$= 200GeV Cu+Cu Collisions. Phys. Rev. Lett., 101:122301 (2008)
- Cold Nuclear Matter Effects on J/ψ as Constrained by Deuteron-Gold Measurements at $\sqrt{s_{NN}}$= 200GeV. Phys. Rev., C77:024912 (2008)
- Cold Nuclear Matter Effects on J/ψ Yields as a Function of Rapidity and Nuclear Geometry in Deuteron-Gold Collisions at $\sqrt{s_{NN}}$= 200GeV. Phys. Rev. Lett., 107:142301 (2011)
- J/ψ suppression at forward rapidity in Au+Au collisions at $\sqrt{s_{NN}}$= 200GeV Phys. Rev. C 84, 054912 (2011)

Physics publications (2) phenomenology

- Cold nuclear matter effects on J/ψ production: Intrinsic and extrinsic transverse momentum effects. Phys. Lett. B680 (2009) 50-55
- Centrality, Rapidity and Transverse-Momentum Dependence of Cold Nuclear Matter Effects on J/ψ Production in d+Au, Cu+Cu and Au+Au Collisions at $\sqrt{s_{NN}}$= 200GeV. Phys. Rev. C81 (2010) 064911
- Gluon EMC effect and fractional energy loss in Upsilon production in dAucollisions at RHIC arXiv:1110.5047 [hep-ph]

Hardware

The PHENIX detector

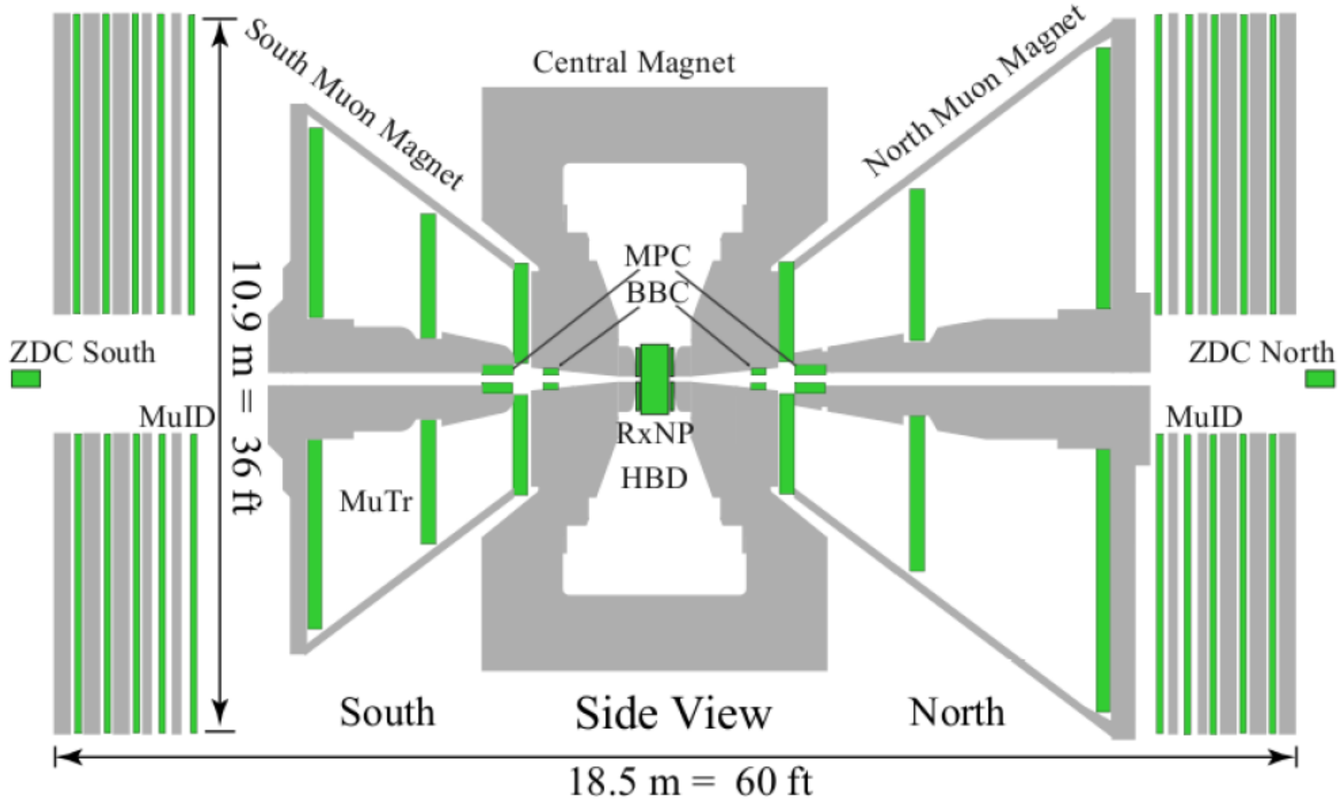


Central arm
hadrons; photons; electrons
p>0.2 GeV/c
$|y|<0.35$
$\Delta\Phi=\pi$
$J/\Psi \rightarrow e^+e^-$

Muon arms
p>2 GeV/c
|y| E [1.2,2.4]
$\Delta\Phi=2\pi$
$J/\Psi \rightarrow \mu^+\mu^-$

Global detectors
(BBC, ZDC)
Provide vertex position and collision centrality

PHENIX muon arms

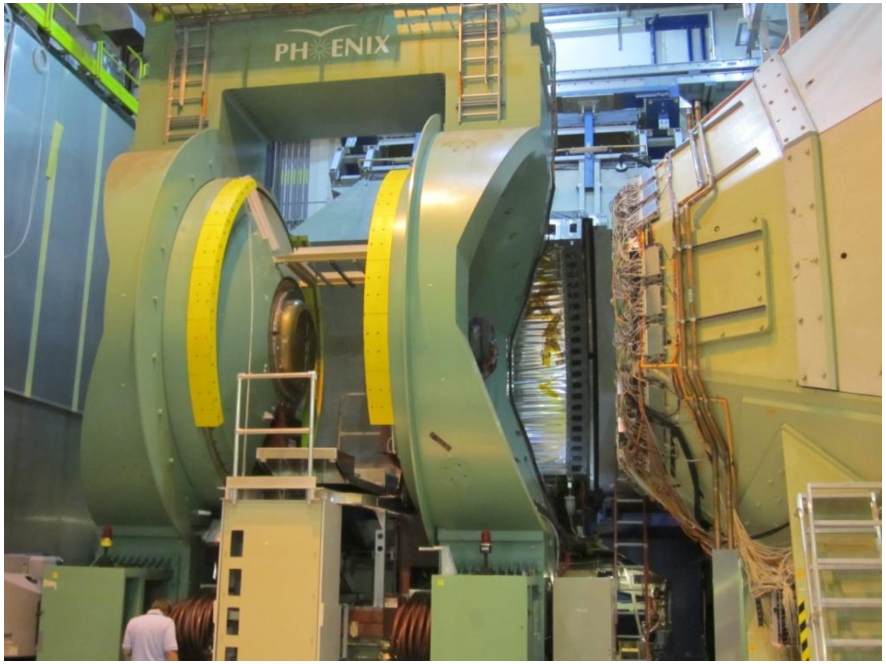


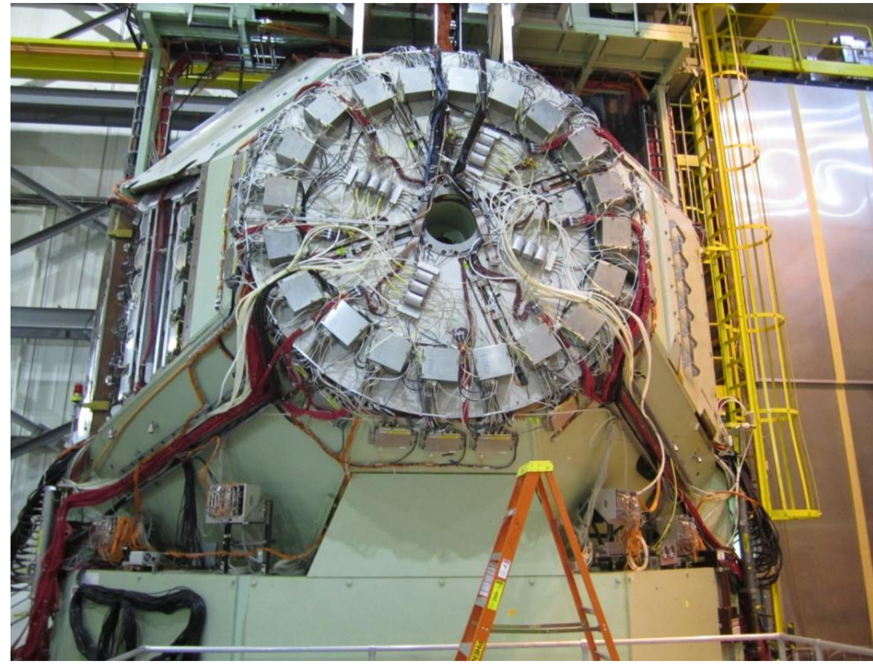
Front absorber to stop hadrons

MuTR: 3 stations of cathode strip chambers with radial magnetic field for momentum measurement

MuID: 5 detection planes (X and Y) and absorber, for muon selection and trigger

The PHENIX detector





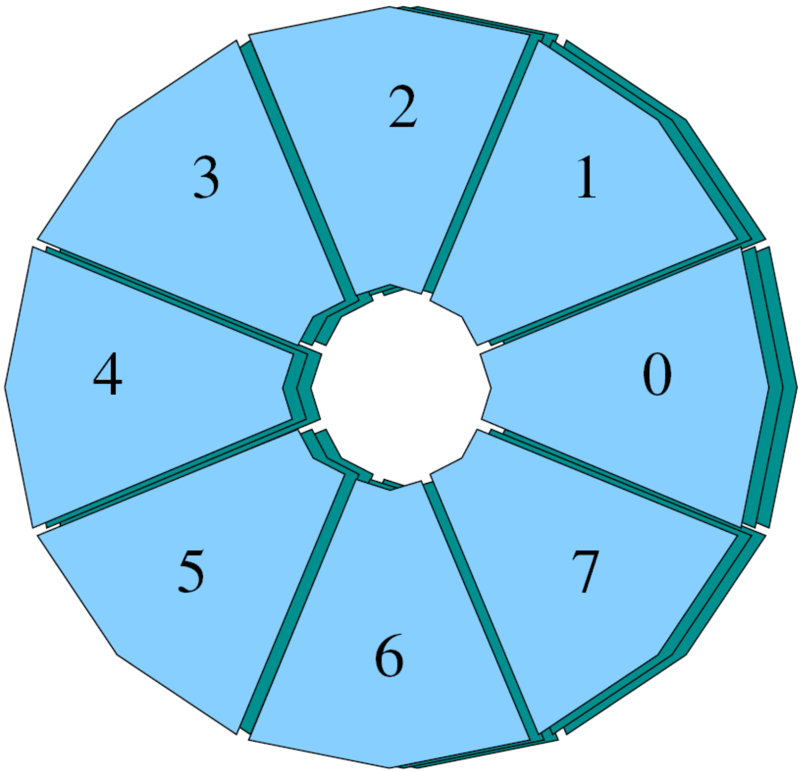
PHENIX detector, with central and South muon arm removed.

PHENIX North muon arm.

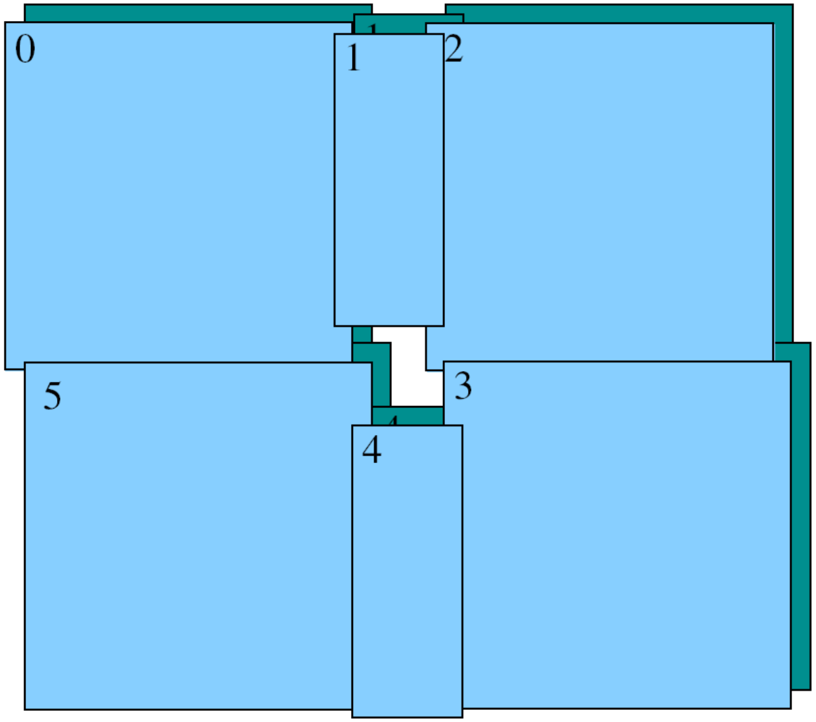
Software

Detector layout

Segmentation of one MuTr Station



Segmentation of one MuID Gap



8 Octants (16 half-octants) for each MuTR cathode plane.

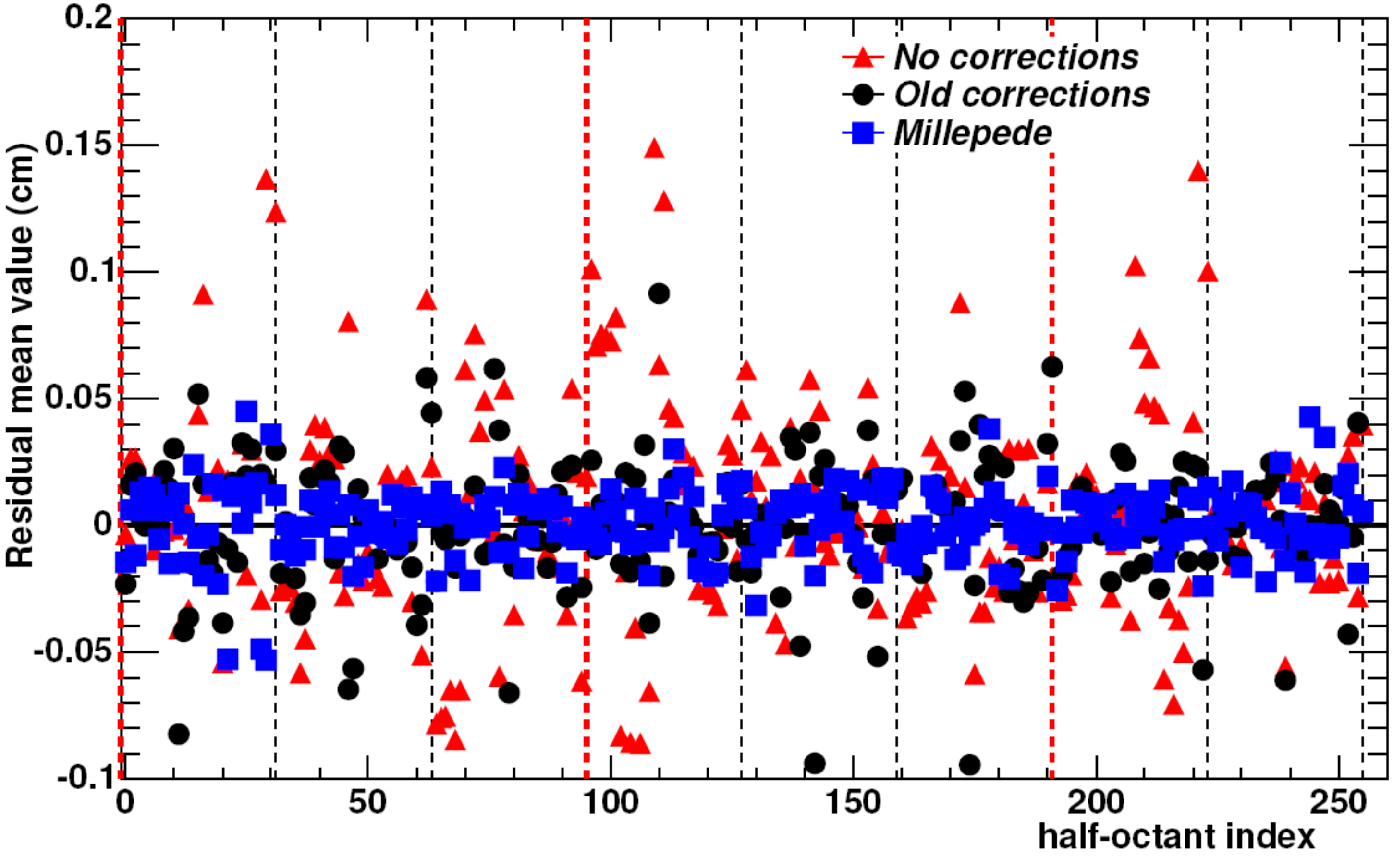
2x6 panels for each MuID plane.

In total 328 independent detector elements in the MuTr and MuID

Detector alignment

Global alignment procedure based on the simultaneous minimization of the chi-square of many tracks with respect to both track parameters and alignment parameters. No iterations needed.

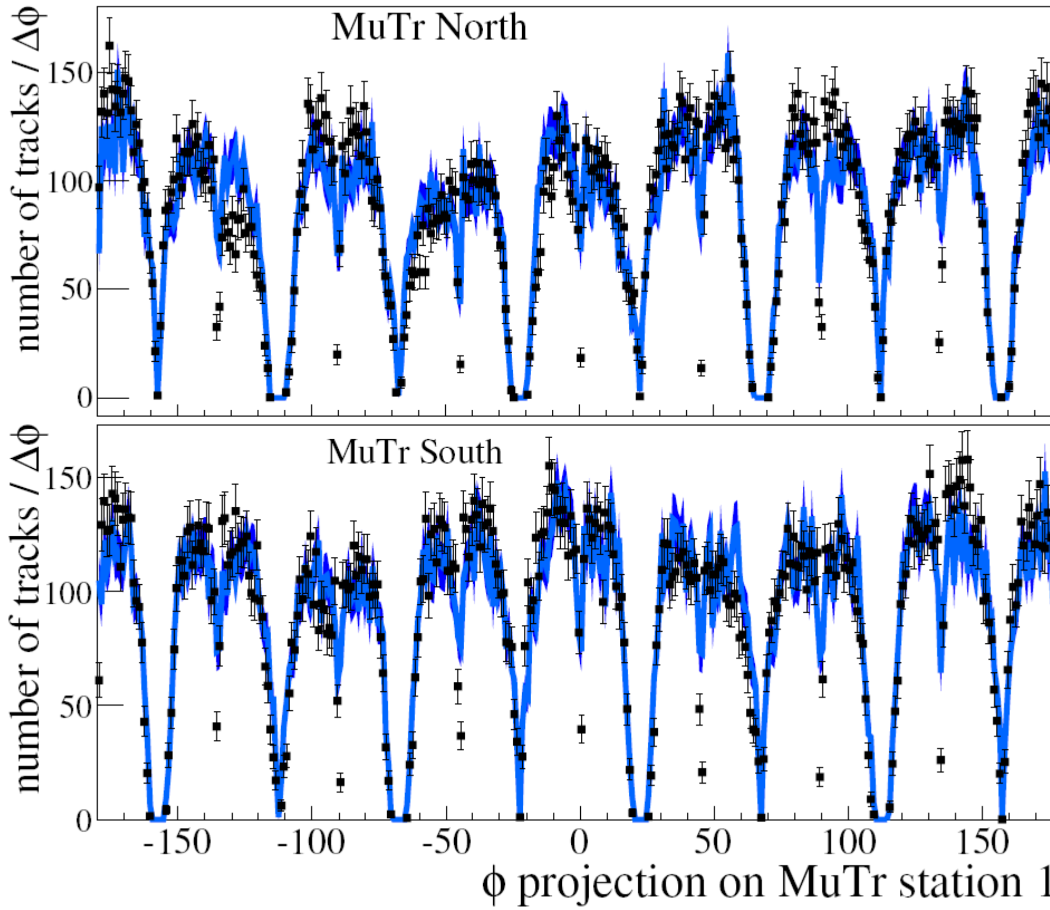
Mean value of the residual distribution vs detector element ID



Detector simulations

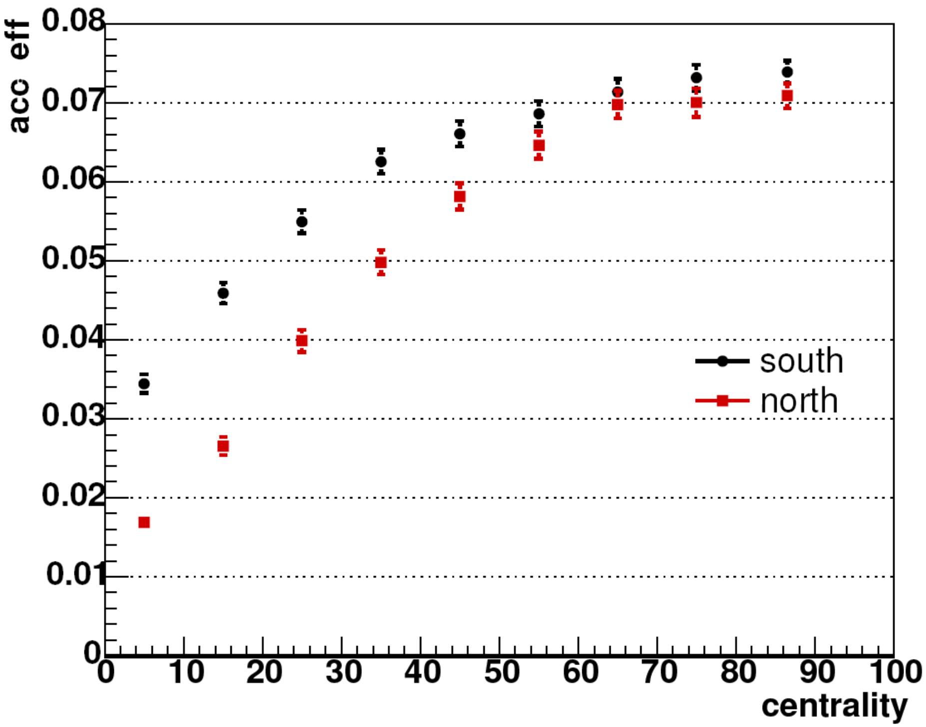
Simulations are needed to correct measured quantities from detector biases and obtain absolute quantities (cross-sections; asymmetries)

This requires that the detector properties are perfectly simulated (geometry, alignment, calibrations, dead areas)

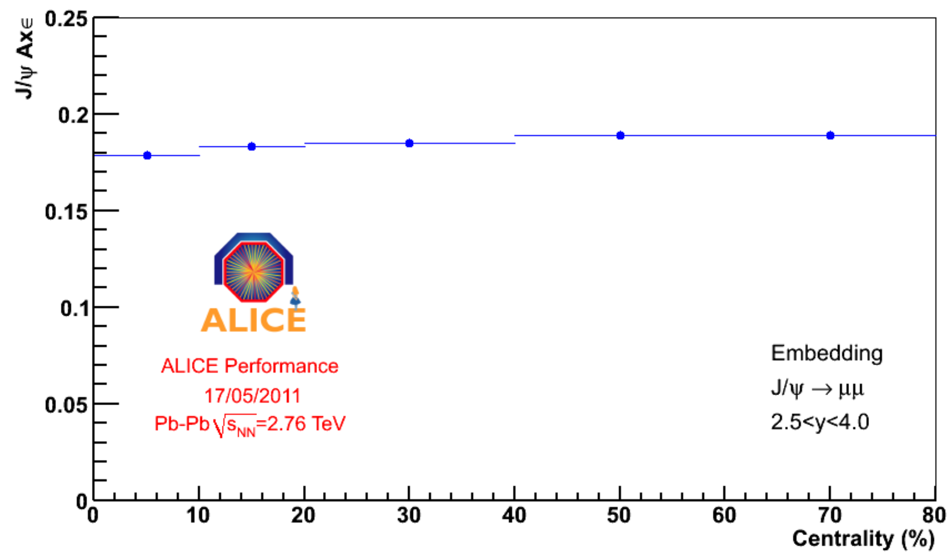


Detector performances

J/ψ acc x eff correction vs centrality in Au+Au collisions @PHENIX



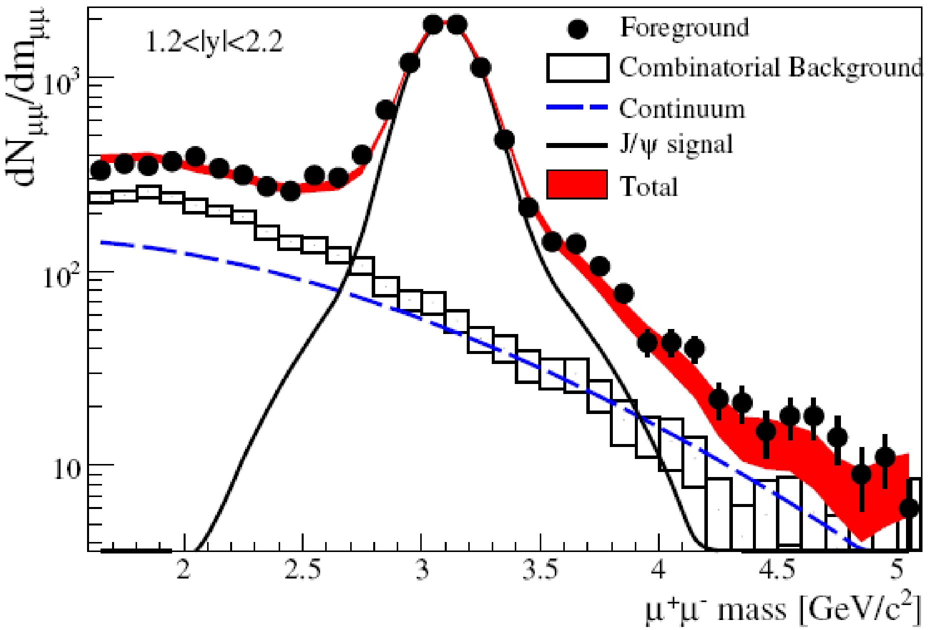
J/ψ acc x eff corrections vs centrality in Pb+Pb collisions @ALICE



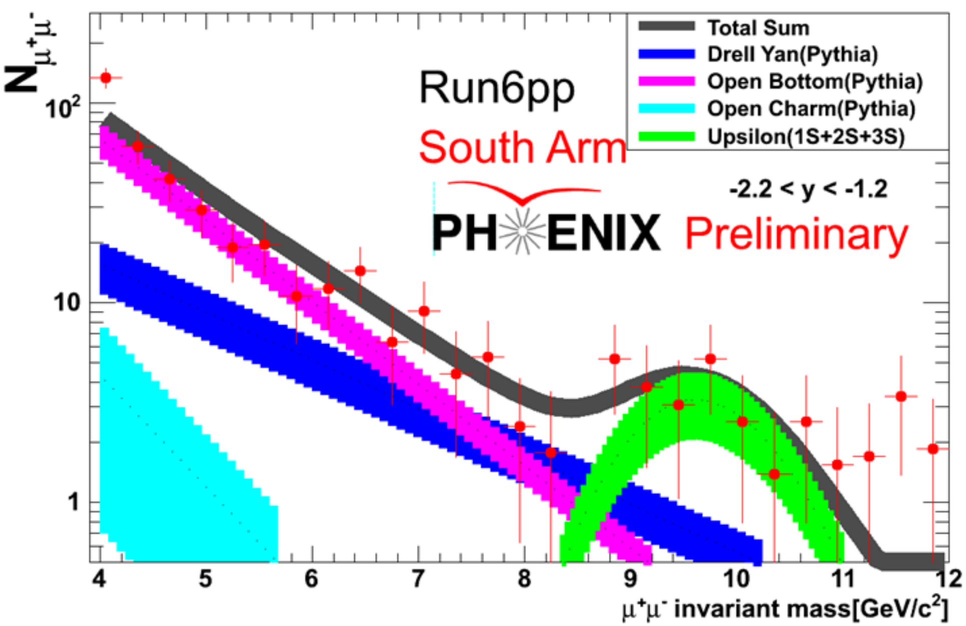
Decrease of the acc x eff corrections is observed for more central collisions. Effect is much stronger with PHENIX muon arms than with ALICE, which is attributed to the much higher segmentation of the ALICE muon arm.

Physics

di-muon invariant mass distributions

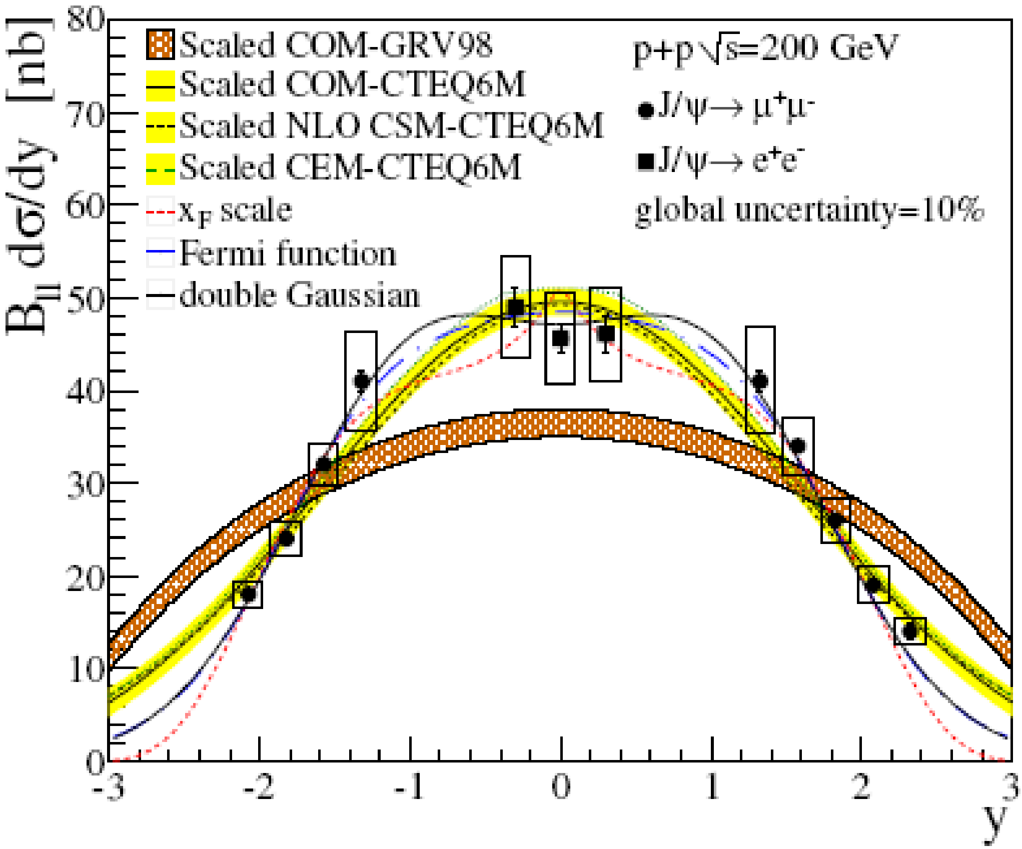


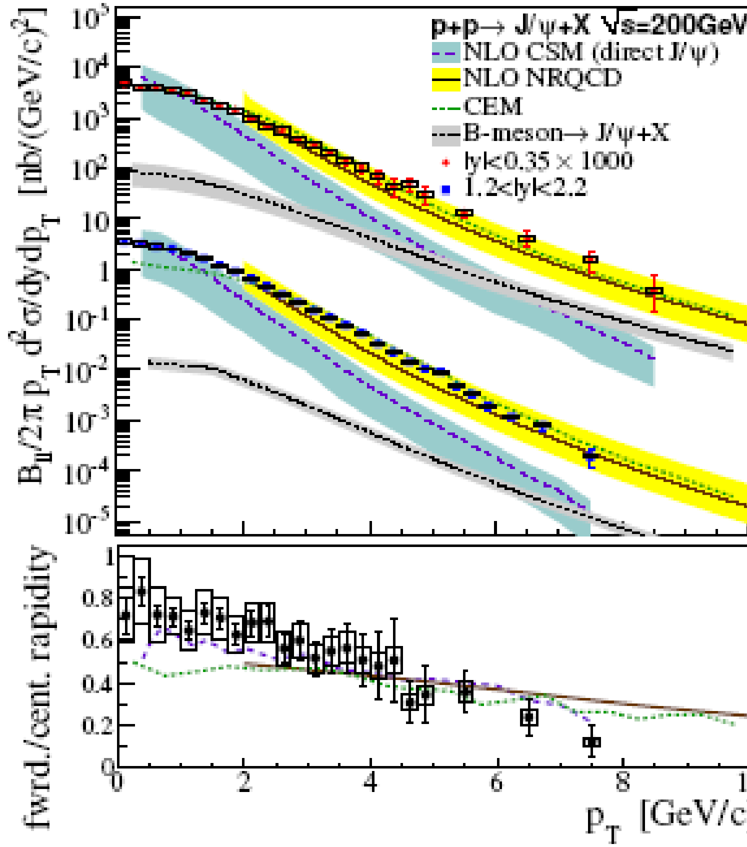
Clear J/ψ peak is observed.
Some excess at higher mass attributed to ψ’
J/ψ mass resolution ~ 170 MeV



Excess over estimated background is measured at the upsilon mass.
Width of the distribution is about 1 GeV (for all three upsilon states)
Statistics is very limited

J/ψ production in p+p collisions





J/ψ production cross-section in p+p collisions; left: vs rapidity, right: vs p_T

Curves are (arbitrarily scaled) model calculations, that differ in

- the set of input parton distribution functions
- the J/ψ production mechanism (neutralization of the ccbar pair)

Cold nuclear matter effects (CNM)

Anything that can modify the production of heavy quarkonia in heavy nuclei collisions (as opposed to p+p) in absence of a QGP

Initial state effects:

- Energy loss of the incoming parton
- Modification of the parton distribution functions (npdf)
- Gluon saturation at low *x* (CGC)

Final state effects:

Dissociation/breakup of the J/ψ (or precursor $c\bar{c}$ quasi-bound state)
Modeled using a break-up cross-section $\sigma_{breakup}$

Quantification of nuclear effects

Nuclear modification factor:

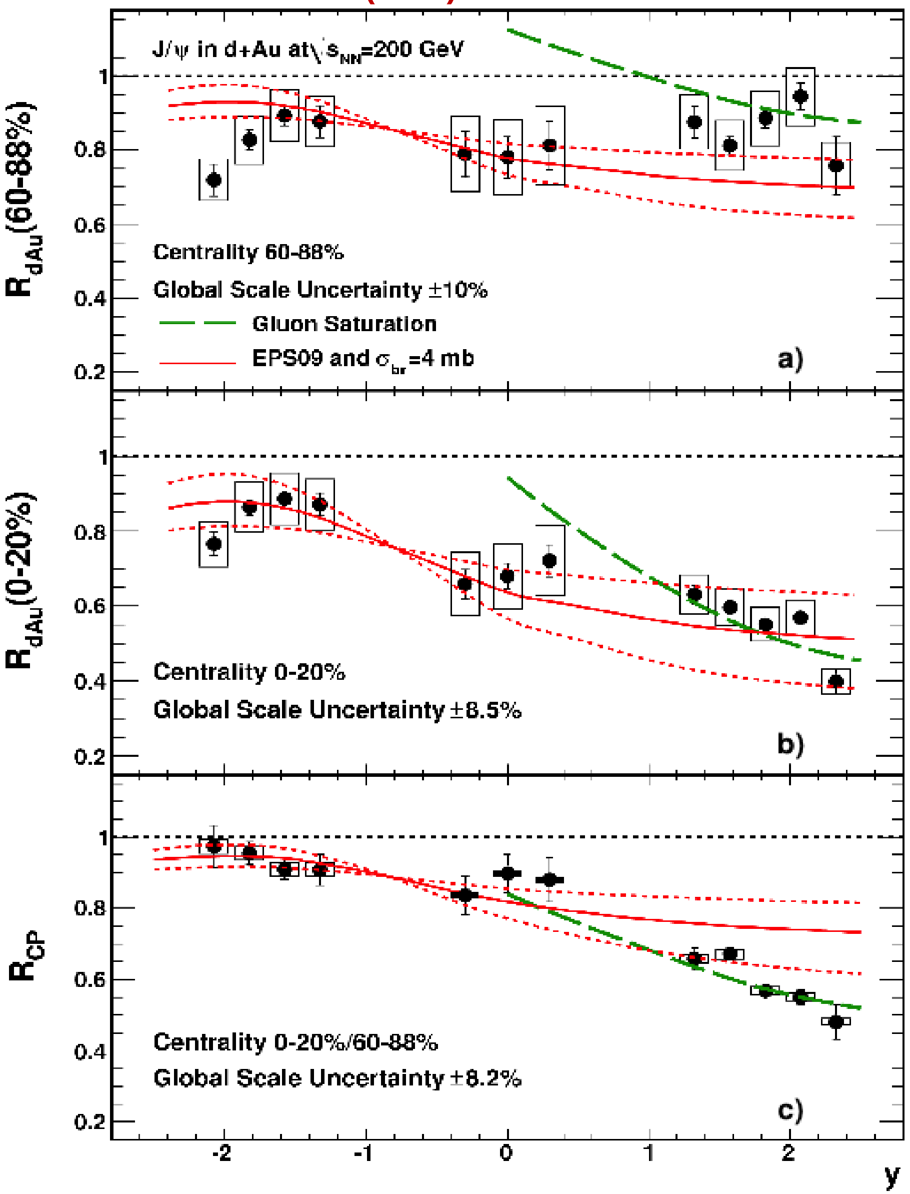
$$R_{d+\mathrm{Au}} = \frac{dN^{\mathrm{J}/\psi}_{d+\mathrm{Au}}/dy}{\langle N_{\mathrm{coll}}\rangle dN^{\mathrm{J}/\psi}_{p+p}/dy}$$

Central to peripheral ratio:

$$R_{\mathrm{CP}} = \frac{dN^{\mathrm{J}/\psi}_{\mathrm{central}}/dy}{dN^{\mathrm{J}/\psi}_{\mathrm{peripheral}}/dy} \cdot \frac{\langle N_{\mathrm{coll}}\rangle_{\mathrm{peripheral}}}{\langle N_{\mathrm{coll}}\rangle_{\mathrm{central}}}$$

npdf + $\sigma_{breakup}$ vs (2008) data

arXiv:1010.1246 (2010)



npdf + breakup cross-section

- Take an npdf prescription (EPS09)
- Add a breakup cross-section
- Calculate CNM as a function of the collision centrality
- Compare to data.

At forward rapidity, this approach (red lines) cannot describe both the peripheral and the central data.

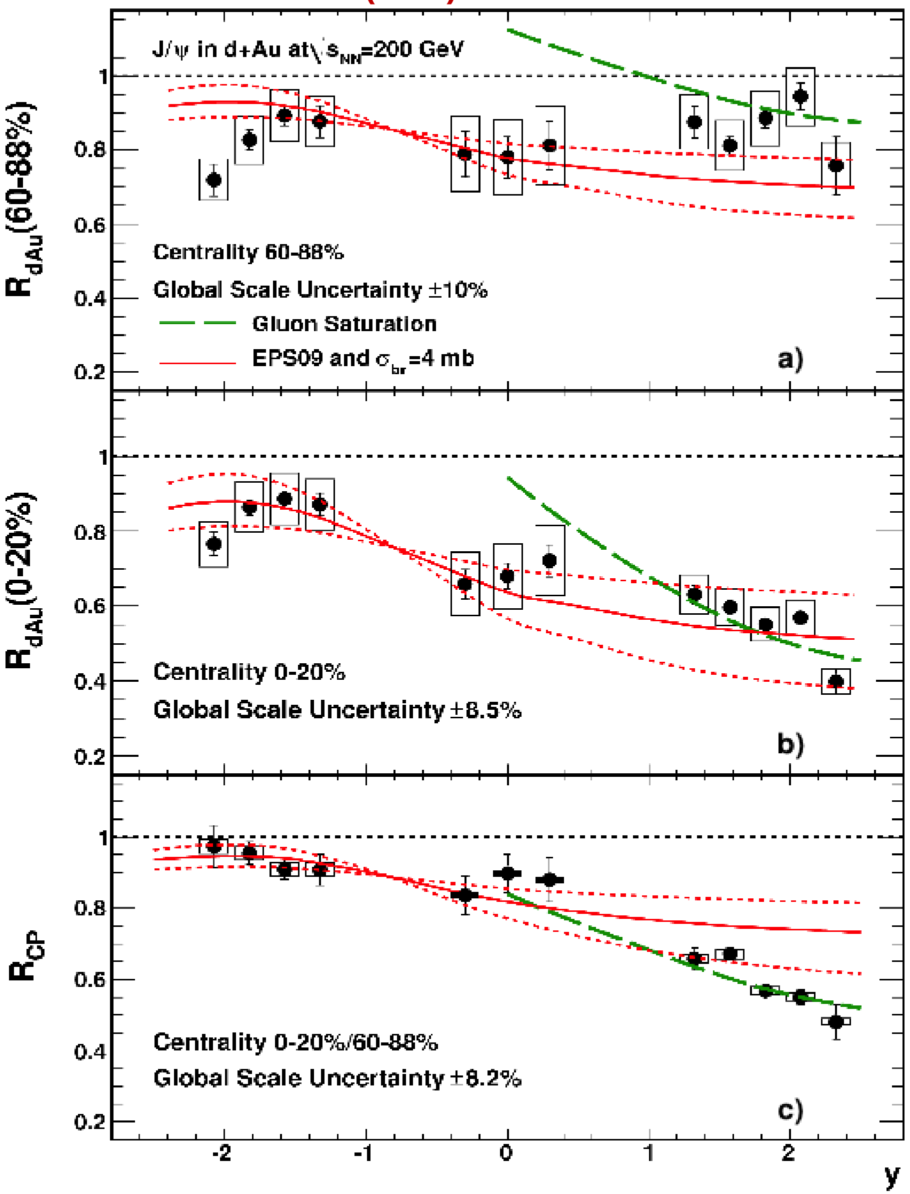
This is best illustrated by forming the ratio of the two (Rcp)

Gluon saturation:

On the other hand, data are reasonably well reproduced at forward rapidity by CGC (green lines) for all centralities.

npdf + $\sigma_{breakup}$ vs (2008) data

arXiv:1010.1246 (2010)



npdf + breakup cross-section

More remarks on the red lines:

- These calculations are made assuming 2+1 production mechanism (aka intrinsic) for the J/ψ. Using 2+2 production mechanism (extrinsic) does not help, since this damp the rapidity dependency of the shadowing effect, missing the forward rapidity points even more.
- Other npdf sets, with extreme shadowing (namely EPS08) do a better job at reproducing the most central forward rapidity points but also fail for peripheral collisions.

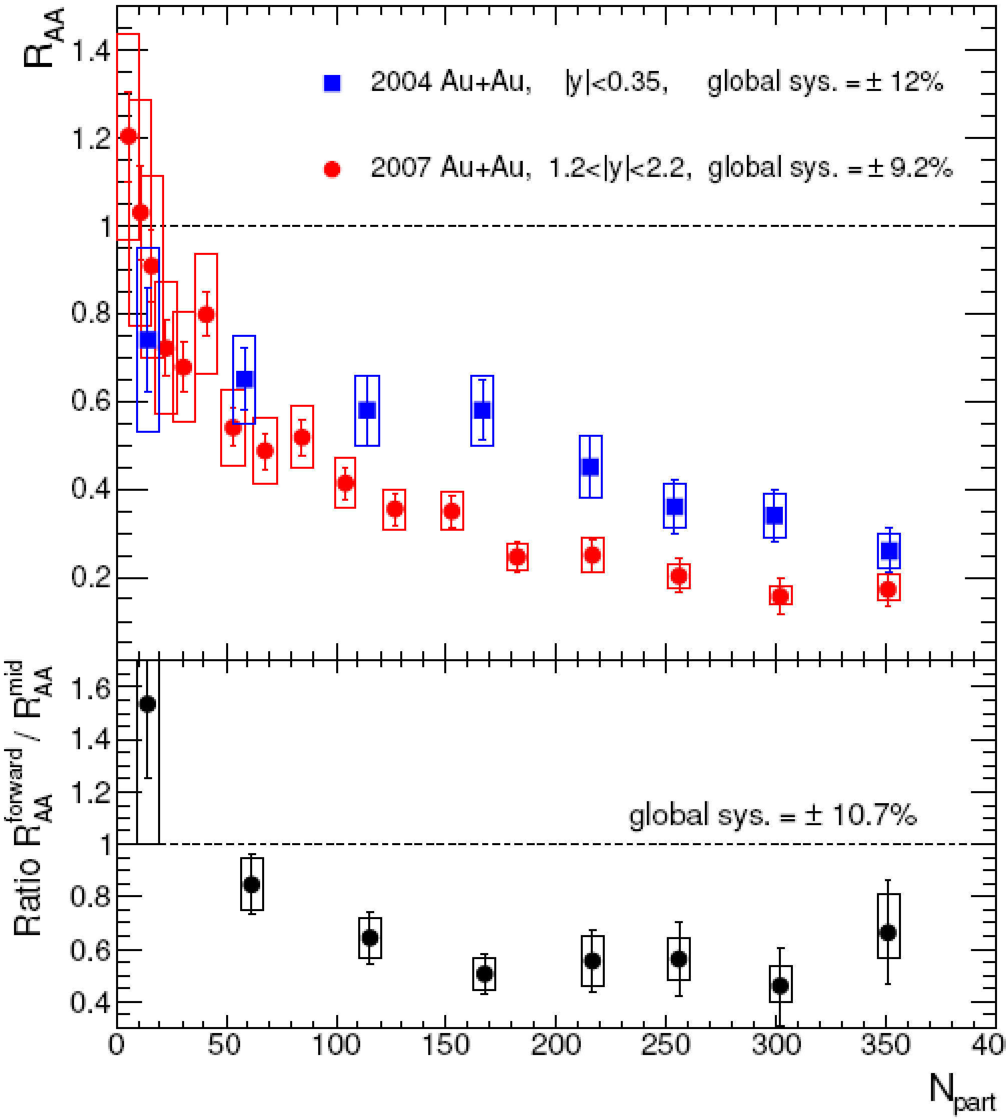
J/ψ production in Au-Au collisions (1)

J/ψ R_{AA} vs centrality in Au+Au collision at mid and forward rapidity.

A suppression is observed for central collisions at both rapidities.

Suppression is larger as forward rapidity than at mid rapidity, which is counter-intuitive, based on energy density arguments.

Latest calculations suggest that this property would be due to cold nuclear matter effects.

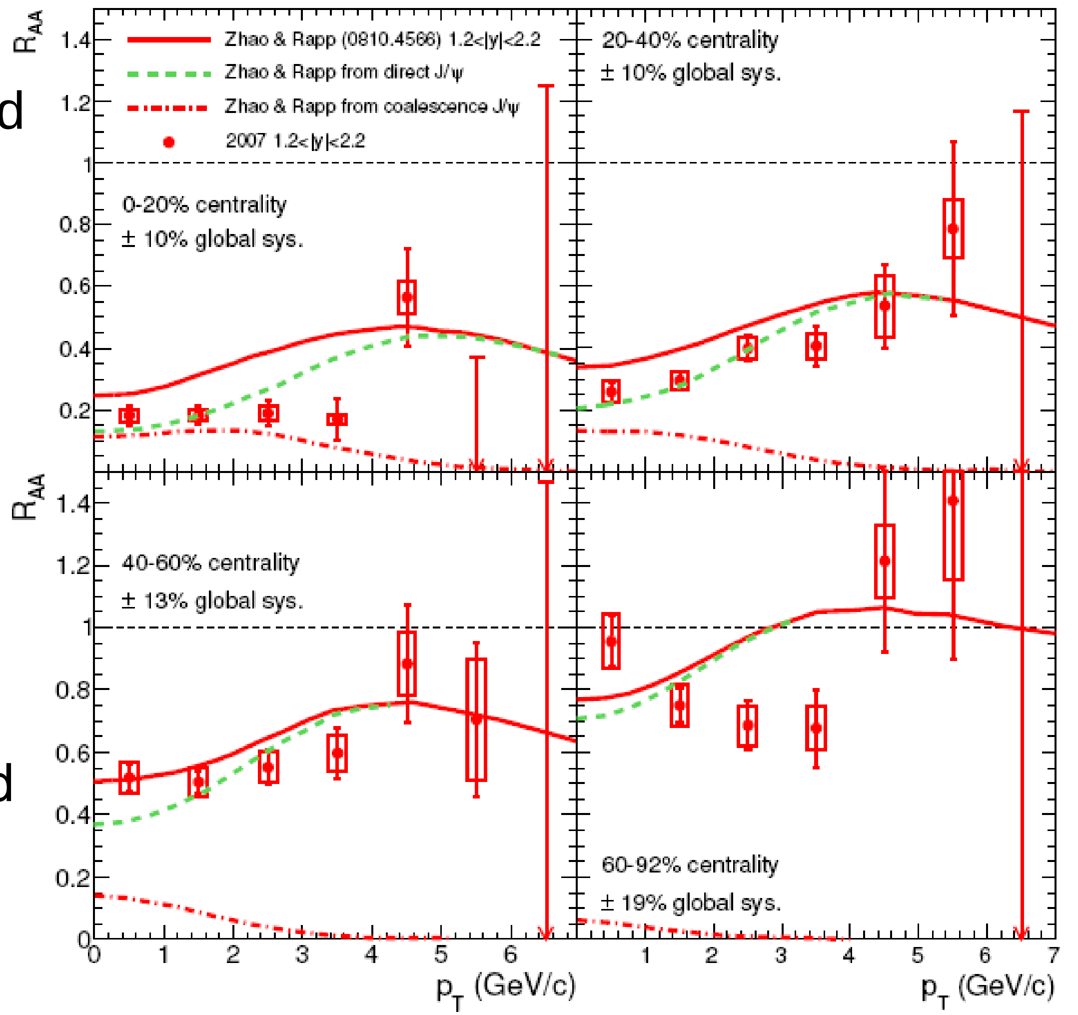


J/ψ production in Au-Au collisions (2)

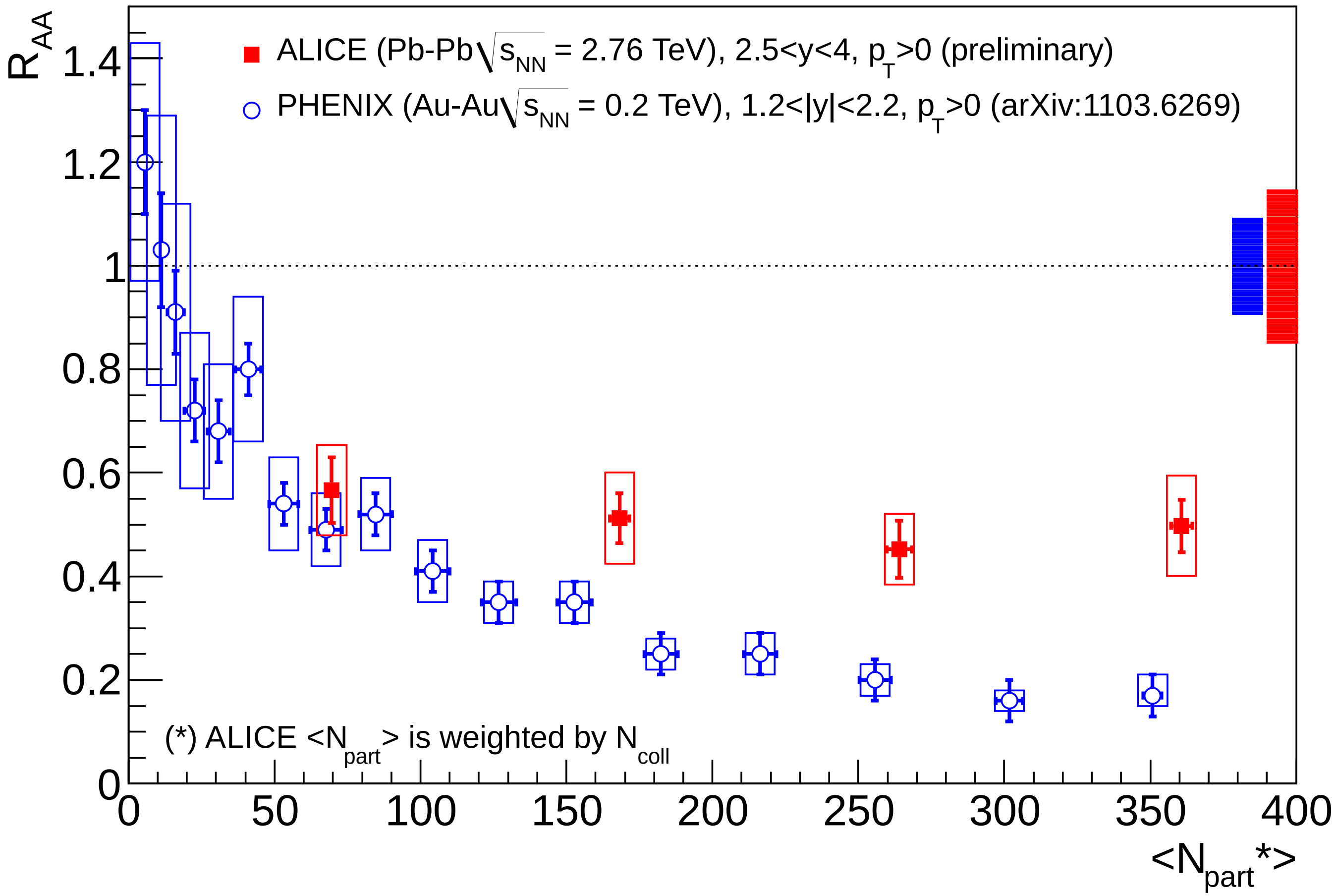
PHENIX data have been compared to many models (here vs p_T and centrality)

This model (Zhao and Rapp) includes:

- Cold nuclear matter estimates guided by 2008 PHENIX d+Au R_{CP} data.
- prompt J/ψ dissociation in QGP
- J/ψ regeneration by uncorrelated cc pair recombination
- Feed-down contributions from B



J/ψ production in Pb-Pb collisions at LHC



Less suppression observed at LHC than at RHIC (forward rapidity), which could be attributed to the onset of recombination.
But cold nuclear matter effects could be quite different (more shadowing at LHC, but less to no nuclear absorption)

Besides, x axis (N_{part}) might not be the relevant one

Questions from referees (1)

- **Are there maintenance works to be provided from IRFU to PHENIX ?**
  No
- **What are the key measurements missing for a firm conclusion ?**
  Hard to answer at RHIC.
  Qualitatively Hot matter effects on J/psi are established.
  Quantitatively (understand which effects are at play and in which proportion) is harder, and requires notably understanding the CNM effects.
- **Are the effects of cold matter better understood ?**
  Better measured, yes: they are large, can't be ignored, and data are already very constraining.
  Better understood, well … there is no model that can reproduce the full rapidity dependence of J/ψ R_{dAu}

Questions from referees (2)

- **And how are the present LHC Pb-Pb data looking like in that respect ?**
  absorption cross-section is expected to be smaller, or zero;
  predictions from gluon nPdf are readily available;
  no prediction from CGC (that I know of);
  final state energy loss is largely unconstrained;
  you need a p+Pb run for a direct measurement.
- **Are the requirements for the measurement of upsilon resonances fulfilled by the Alice di-muon arm yet**
  yes (but Javier would comment better);
  bottleneck today is luminosity. Wait for 2011 data.